

BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

# Plant genetic resources

A review of current research and future needs

Edited by Dr M. Ehsan Dulloo, Bioversity International, Italy



# Contents

---

Series list	x
Foreword	xvii
Acknowledgements	xx
Introduction	xxi

## **Part 1 Importance and value of conservation and use of plant genetic diversity**

1	Plant genetic resources for food and agriculture for sustainable development	3
	<i>Chikelu Mba, Seeds and Plant Genetic Resources Team – Food and Agriculture Organization of the United Nations, Italy; M. Ehsan Dulloo, Bioversity International, Italy; and Kent Nnadozie, Secretariat of the International Treaty on Plant Genetic Resources for Food and Agriculture – Food and Agriculture Organization of the United Nations, Italy</i>	
	1 Introduction	3
	2 Plant genetic resources for food and agriculture (PGRFA): a common concern for all countries	5
	3 International agreements supporting the global system on PGRFA	7
	4 Global instruments supporting the global system on PGRFA	8
	5 Global mechanisms supporting the global system on PGRFA	10
	6 Codes of conduct and standards supporting the global system on PGRFA	11
	7 The conservation of PGRFA	12
	8 Pre-breeding and conservation of PGRFA	15
	9 Plant breeding techniques to introduce desirable traits from PGRFA	16
	10 Seed delivery systems	23
	11 Conclusion	24
	12 Where to look for further information	26
	13 References	27

---

2	Valuing plant genetic resources in genebanks: Past, present and future	35
	<i>Melinda Smale, Michigan State University, USA; and Nelissa Jamora and Luigi Guarino, Global Crop Diversity Trust, Germany</i>	
	1 Introduction	35
	2 Past research on genebanks	37
	3 Current research on genebanks	40
	4 Future trends in research	47
	5 Conclusion	48
	6 Where to look for further information	49
	7 References	49
3	Monitoring plant genetic resources for food and agriculture	55
	<i>M. Ehsan Dulloo, Bioversity International, Italy; Prishnee Bissessur, Bioversity International, Mauritius; and Jai Rana, Bioversity International, India</i>	
	1 Introduction	55
	2 Monitoring species diversity	57
	3 Monitoring varietal diversity	61
	4 Monitoring genetic diversity	65
	5 Targets and indicators framework for monitoring genetic diversity	67
	6 Conclusion and future trends in research	69
	7 Where to look for further information	72
	8 References	73
4	Improving the global exchange of germplasm for crop breeding	81
	<i>Selim Louafi, UMR AGAP Institut, CIRAD, University of Montpellier, INRAE, Institut Agro, Montpellier, France; and Eric Welch, Arizona State University, USA</i>	
	1 Introduction	81
	2 Exchange of germplasm for crop breeding: what are we talking about?	82
	3 Opening the black box of collaborations in plant genetic resources for food and agriculture	87
	4 The germplasm exchange fallacies	92
	5 Conclusion	96
	6 Where to look for further information	97
	7 References	98

## **Part 2 Protecting plant genetic diversity: in-situ and on-farm strategies**

5	Key steps in conservation and use of plant genetic resources: an overview	103
	<i>Nigel Maxted and Joana Magos Brehm, University of Birmingham, UK</i>	

1	Introduction	103
2	A model of plant genetic conservation and use	106
3	Conservation planning	108
4	Conservation: strategies and techniques	121
5	Conservation into utilization	127
6	Conclusion	129
7	Where to look for further information	129
8	References	131
6	Key issues facing genebanks in preserving crop genetic diversity ex situ: overview of the range of challenges <i>Paula Bramel, formally Crop Trust, Germany</i>	139
1	Introduction	139
2	Issues for the composition of ex situ collections	143
3	Issues for routine operations for conservation	144
4	Issues for use of conserved genetic resources	149
5	Conclusion	150
6	Where to look for further information	151
7	References	151
7	Techniques and key issues in collecting crop wild relatives <i>Michael Way, Royal Botanic Gardens, Kew, UK</i>	155
1	Introduction	155
2	Targeting species and regions for collecting	157
3	Identifying target CWR taxa successfully in the field	160
4	Understanding seed development, ripening and dispersal	162
5	Collecting seed at the correct time	164
6	Assessing seed quality and quantity	167
7	Sampling genetic diversity effectively from populations	169
8	Techniques for collecting and post-harvest handling	172
9	Future research directions	177
10	Where to look for further information	179
11	Acknowledgements	180
12	References	180
8	New technologies to improve the ex situ conservation of plant genetic resources <i>Fiona R. Hay, Aarhus University, Denmark; and Sershen, University of the Western Cape &amp; Institute of Natural Resources, South Africa</i>	185
1	Introduction	185
2	Improving the management of orthodox seeds	186
3	Improving the management of recalcitrant-seeded and vegetatively propagated species	198

4	Conclusion and future trends	205
5	Where to look for further information	207
6	References	207
9	The role of the Svalbard Global Seed Vault in preserving crop genetic diversity <i>Åsmund Asdal, Nordic Genetic Resource Centre (NordGen), Sweden</i>	217
1	Introduction	217
2	Storing seeds in the Arctic: establishing the Svalbard Global Seed Vault	218
3	The Seed Vault in a global context	219
4	The Seed Vault facility and its operation	220
5	Case study: the ICARDA withdrawal and re-deposit programme	223
6	Where to look for further information	224
7	References	225
<b>Part 3 Enhancing conservation and use of plant genetic diversity</b>		
10	Community-based conservation of crop genetic resources <i>Stef de Haan, International Potato Center (CIP), Peru</i>	229
1	Introduction	229
2	Autonomous community-based conservation	231
3	Exogenous incentives for community-based conservation	234
4	Monitoring community-based conservation	238
5	Summary and future research outlook	240
6	References	241
11	Participatory plant breeding programs to optimize use of crop genetic resources <i>Margaret Smith, Cornell University, USA; and J. C. Dawson, University of Wisconsin-Madison, USA</i>	251
1	Introduction	251
2	Methodologies to assess variety preference	254
3	Participatory plant breeding based on traditional/local varieties	261
4	Challenges and limitations	264
5	Summary	265
6	Where to look for further information	266
7	References	267
12	Seed systems and diversity <i>Niels Louwaars, Plantum and Wageningen University, Law Group, The Netherlands</i>	271
1	Introduction	271
2	Seed systems and diversity in farmers' fields	273

3	Supporting diversity in farmers' seed systems	274
4	Supporting diversity in formal seed systems	277
5	Policies and regulations	280
6	Future trends in research	283
7	Conclusions	283
8	Where to look for further information	284
9	References	284
13	DNA-based screening of <i>Brassica</i> germplasm for sustainable and enhanced crop production	289
	<i>Yueqi Zhang, The University of Western Australia, Australia; Ting Xiang Neik, Sunway College Kuala Lumpur, Malaysia; and Junrey C. Amas, Aldrin Y. Cantila, Nur Shuhadah Mohd Saad, Tingting Wu and Jacqueline Batley, The University of Western Australia, Australia</i>	
1	Introduction	289
2	Management and conservation of <i>Brassica</i> germplasm	291
3	Sustainable management of resistance to biotic stress	299
4	Sustainable management of resistance to abiotic stresses	303
5	Enhancing yield and nutritional related traits	305
6	Conclusion and future trends	309
7	Where to look for further information	309
8	References	309
	Index	319

# Foreword

---

After several promising years, hunger and malnutrition are again on the rise. The latest edition of *'The State of Food Security and Nutrition in the World'*, published jointly by five UN agencies<sup>1</sup>, estimated that in 2019 almost 690 million people went hungry, an increase of nearly 60 million over the previous five years. This occurred against a complex and alarming backdrop of growing economic, racial, and social inequality, persistent and widespread environmental degradation, continually expanding human populations, rapidly changing climates and a weakening of the architecture of international cooperation. Most recently, the global disruption caused by COVID-19 has further exacerbated the situation.

Within this web of inter-connected challenges, biodiversity continues to be lost at an alarming rate in spite of the best efforts of many individuals, organizations and nations. A report published by the Convention on Biological Diversity in September 2020, *'Global Biodiversity Outlook 5'*, concluded that none of the 20 Aichi biodiversity targets agreed to by the parties to the Convention in 2010 had been fully achieved, and only six had been partially achieved. The failure to adequately stem the loss of biodiversity has significant implications not only for the environment but also for human wellbeing, even survival.

A critically important component of biodiversity is that which feeds and clothes us, in particular the genetic diversity within and among our domesticated animals, cultivated crops and their wild relatives. This vast diversity underpins agriculture, and its deployment helps us to meet the challenges and opportunities of today's world and as well as the unknown circumstances that will prevail tomorrow.

In 2019, the Food and Agriculture Organization of the United Nations (FAO), published *'The State of the World's Biodiversity for Food and Agriculture'*. The report pointed out that as in the case of biodiversity in general, many components of agricultural biodiversity remain under threat. For crops, neglected and underused species in particular remain under-represented in *ex situ* collections and in many parts of the world the use of landraces and traditional farmer varieties continues to decline in local farming systems. However, the situation is highly complex, and the news is not all bad, especially for those crops for which past conservation efforts are paying off handsomely. Although a great deal remains to be done, many countries are expanding the range of genetic resources that they conserve *ex situ* and many farmers who have adopted modern varieties also continue to maintain traditional landraces.

<sup>1</sup> FAO, IFAD, UNICEF, WFP and WHO

But there is no room for complacency and the situation for crop wild relatives is even more concerning. This is particularly so in regions experiencing severe climate change and widespread degradation of habitats, and where species migration is limited by ecogeographical and other barriers.

Why should we be concerned? For the simple reason that agricultural genetic diversity represents a very powerful tool in our efforts to meet a wide variety of current and future challenges. The genetic resources of our crops underpin our ability to breed new cultivars that can help make agriculture more sustainable and productive within a rapidly changing world. Such cultivars could, for example, provide more nutritious food, novel products, be more resilient to pests, disease and environmental stresses, or have the ability to sequester more carbon.

Thus, crop genetic diversity provides a basis for making significant inroads into improving the lives and wellbeing of humanity as well as the environment in which we all live. However, in order to play this role effectively, genetic diversity must be safely conserved and wisely used, and in both of these areas we can do better. Although we know much about how best to safeguard and use genetic resources there are still major areas where further research is needed. This book makes a very important contribution to this effort through providing an up-to-date overview of the current state of scientific research and provides some invaluable pointers to future research needs and opportunities.

This book does not go into detail about the current state of scientific plant breeding as this is a topic that has been well covered in other recent publications. What it provides is an extensive, much-needed and detailed coverage of a broad range of topics, from the importance and value of plant genetic resources and key methods for conserving them, through to their international exchange and local dissemination through more effective seed systems.

The senior editor of the book, Ehsan Dulloo, is to be congratulated on such a timely and useful publication. Furthermore, the range of authors of the individual chapters and the institutions they represent is truly impressive and reads like a Who's Who of plant genetic resources!

At the time of writing, the parties to the Convention on Biological Diversity are working to finalize a '*post 2020 global biodiversity framework*' to supersede the Aichi targets. The framework aims to act as a steppingstone on the way to achieving the Convention's 2050 Vision: '*By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people.*' The current version of the framework envisages several long-term goals for biodiversity in general, including maintaining genetic diversity, and the fair and equitable sharing of benefits arising from its use. It is greatly to be hoped that in the final, agreed text this will be further built upon to ensure that the importance of

genetic resources for food and agriculture, and their potential contribution to achieving the Sustainable Development Goals are fully recognized.

I commend this book to all who share these aims.

Geoffrey Hawtin OBE PhD

Former Director General, Bioversity International and

Centro Internacional de Agricultura Tropical (CIAT)

Founding CEO, Global Crop Diversity Trust

January 2021

# Introduction

---

Plant genetic diversity is fundamental for ensuring global food and nutrition security. Its importance cannot be underestimated as it provides the genetic materials for humankind to continue produce food sustainably in the face of global challenges such as pest and diseases, land degradation, climate change and other socio-economic changes that are occurring today and that will take place in future. While at the global level, their importance is widely recognised as evidenced by the Convention on Biological Diversity and the International Treaty on Plant Genetic Resources for Food and Agriculture, and political processes established for monitoring the conservation and use of genetic resources, we find at the national and local levels that the conservation and use of plant genetic diversity are not getting the attention they deserve with the result that much of the diversity are eroding away, thereby undermining agriculture as a whole. Some key challenges include a narrowing genetic base for many key crops, the loss of landraces and wild relatives, due to agricultural intensification and urbanisation, land and soil degradation, the lack of support to minor and under-utilized crops that are locally and regional important. There is a need to develop the role of existing gene banks from repository of genetic diversity to enablers of the flow of germplasm and genetic information for breeding more robust varieties. There is equally an urgent need to stop the erosion of genetic diversity from their sites where they have developed their distinctive characteristics (in situ) such that the diversity among them can continue to evolve and develop traits for future use.

This volume examines the wealth of research addressing these challenges and the opportunity for a more integrated, global approach to protecting and leveraging plant genetic diversity for a more sustainable agriculture. Part 1 assesses the importance of valuing conservation and the use plant genetic diversity. Part 2 discusses protecting plant genetic diversity with *in-situ* and on-farm strategies. The final section reviews ways of enhancing conservation and the use of plant genetic diversity, including community-based conservation of crop genetic resources, participatory plant breeding programmes and more effective seed systems.

## **Part 1 Importance and value of conservation and use of plant genetic diversity**

Part 1 of the book begins with a discussion of plant genetic resources for food and agriculture for sustainable development. Chapter 1 reviews relevant international agreements, instruments and mechanisms, which address

the conservation, sustainable use and access and benefit-sharing for these resources along with their remarkable contributions to food security and nutrition. The chapter also highlights the state-of-the-art for the scientific and technological methods used to conserve and add value through genetic gains to these resources. Underscoring the importance of collaborations at various scales, the authors call for continued global coordination and partnerships on the internationally agreed activities for conserving effectively and deriving the most benefits sustainably from these irreplaceable resources.

Chapter 2 examines valuing past, present and future plant genetic resources in genebanks. The chapter summarises the main messages from applied economics literature on genebank values that began in the late 1990s, a recent set of studies undertaken by the CGIAR Genebank Platform and Crop Diversity Trust, and assessments of national genebanks. Three points are salient: the value of information; the demand for a diversity of approaches to document the diversity of ways that genebanks benefit society; and the need to establish priorities for collecting and conservation based on cost-effectiveness. Cost-effectiveness will require a) carefully targeted investments in characterization, evaluation, and genotyping, along with management of the resulting data, and its use to develop packages of breeder- and researcher-oriented materials, and b) investment in supportive research and various organizational optimization procedures, including automation.

The subject of Chapter 3 is monitoring plant genetic resources for food and agriculture. The chapter reviews the methodologies developed to assess the extent of diversity of PGRFA at species, variety, and genetic level and examines the efforts made at global level in monitoring them at different scales. Efforts have been made to halt the loss of biodiversity (including genetic diversity) by United Nations Organizations (FAO, UNEP, UN) at setting of global targets (second Global Plan of Action on conservation and sustainable use of PGRFA, Aichi Targets and Sustainable Development Goals) and indicators have been established to monitor progress towards them. Yet none of the targets on genetic diversity have been achieved, due to a lack of implementable monitoring system that would allow progress to be accurately monitored. Further research is needed to improve the methodologies for monitoring plant genetic resources, particularly at the varietal and genetic level. The chapter discusses the opportunities and challenges as well as provides recommendations for future conservation and monitoring strategies that may safeguard PGRFA for posterity.

The final chapter of Part 1 reviews improving the global exchange of germplasm for crop breeding. Different norms, rules and practices organize the exchange of germplasm to address broader global challenges such as advancement of science and innovation, food security, sustainable agriculture or global equity. Some of these institutions are now embedded in various

treaties and national regulations. Chapter 4 claims that these regulations are not as successful as they could be because they fail to effectively integrate the complexity of the exchange environment. In order to better understand how exchange could be improved, it is important to go beyond a legalistic approach to exchange and look at the broader socio-technical context in which these exchanges take place. By developing an analytical framework that includes several dimensions beyond the regulatory one, this contribution creates the foundation for a more comprehensive approach that acts upon the relationship between germplasm and the diversity of institutional logics, germplasm and its resource system, and germplasm and its social environment.

## **Part 2 Protecting plant genetic diversity: in-situ and on-farm strategies**

The first chapter of Part 2 assesses key steps in conservation and use of plant genetic resources: an overview. Chapter 5 begins by providing an example of a model which includes a series of steps starting with the full range of genetic diversity for all the target plant taxa, through the prioritisation of target taxa, the planning and the implementation of conservation action, leading through characterisation and evaluation, and utilisation in the development of novel crop varieties by farmers and/or breeders. The chapter then goes on to discuss conservation planning which is then followed by a review of the different strategies and techniques that are used in conservation. A section on the link between conservation and utilization is also included, before providing a conclusion that emphasises the importance of maintaining the current wealth of natural plant diversity.

Chapter 6 addresses key issues facing genebanks in preserving crop genetic diversity *ex situ*: an overview of the range of challenges. Local crop genetic diversity is challenged with changes in land use, urbanization, land degradation, changes in agricultural practises, availability of improved varieties, changes in market preference, and the impact of climate change. Efforts have been made to secure plant genetic resources *ex situ* for future use but there are significant issues related to cost effective, efficient, secure, rational, and sustainable long-term *ex situ* conservation. The chapter begins by addressing issues for the composition of *ex situ* collections and moves on to discuss issues for routine operations for conservation. It also highlights issues for the use of conserved genetic resources, before concluding with a summary of why the development of sustainable genebank systems is so important.

The next chapter examines the techniques and key issues in collecting Crop Wild Relatives (CWR). The genetic diversity found in populations of crop wild relatives is an essential resource for future crop breeding, but populations

are at risk of loss before germplasm has been fully conserved in genebanks. Chapter 7 describes best practice for targeting and identifying species, and review knowledge about the variation in wild plant populations to guide the timing of collecting and approaches for genetic sampling. Indicators are presented for seed quality, ripeness and dispersal. Techniques for collection of seed, herbarium vouchers and associated data are reviewed with examples drawn from the Adapting Agriculture to Climate Change (Crop Wild Relative) project. Further research is needed to find optimal approaches for handling of seed to ensure high longevity of seed collections, and improved tools are needed to guide sampling of genetic diversity of crop wild relatives.

Moving on to Chapter 8, this chapter discusses new technologies to improve the *ex-situ* conservation of plant genetic resources. Access to plant genetic resources is fundamental to the development of more resilient and nutritious crops. The efficient and effective conservation of plant genetic resources is therefore key to ensuring global food security. There are more than 1750 genebanks around the world, storing various types of plant germplasm including tissue cultures, seeds, embryos and pollen. The chapter describes some of the recent applications of science and technology to improve the management of genebank collections of orthodox seeds, not least through the introduction of automation. In addition, the chapter looks at how routine cryopreservation procedures are now possible for many species, and how storage procedures for recalcitrant-seeded and vegetatively propagated species continue to evolve given the challenges they present in terms of long-term *ex situ* germplasm conservation.

Part 2 concludes with an analysis of the role of the Svalbard Global Seed Vault in preserving crop genetic diversity. Chapter 9 provides an overview of this facility in Svalbard and describes its operations as well as its functions and status. Genetic material in individual genebanks is potentially vulnerable to being lost (e.g. through conflict or a natural disaster). One important and simple security measure is to ensure that samples of these valuable genetic materials are conserved in more than one place. In this context, the Svalbard Global Seed Vault offers a free of charge service to store duplicate samples of seeds that are conserved in genebanks world-wide.

### **Part 3 Enhancing conservation and use of plant genetic diversity**

The final part of the book begins with a discussion on community-based conservation of crop genetic resources. Chapter 10 explores the current state of research, knowledge and practice of community-based conservation in the context of continued farmer-driven processes and the emergence of diverse external interventions. Autonomous community-based conservation is

largely powered by farmer demand for crop diversity. Cultural, provisioning and regulating ecosystem services play an essential role. It is argued that an enhanced understanding of the drivers and rationales influencing farmers decision-making continues to be essential under the current scenario of accelerated global change. A large and diverse portfolio of exogenous interventions have emerged since on-farm conservation has become a development issue. A variety of different interventions designed to support on-farm conservation for are reviewed. The chapter also highlights the need for an effective monitoring framework for community-based management of crop genetic resources. Such a systems could enhance the measurement, metrics and intelligence underlying the on-farm conservation status of crops and landraces.

Chapter 11 reviews participatory plant breeding programmes to optimize use of crop genetic resources. The chapter summarises a sample of variety evaluation, experimental design, and breeding method innovations that have served as solid approaches for participatory plant breeding (PPB) efforts. With success in PPB comes success in conservation at a local level of useful alleles and allele assemblages in the form of on-farm crop genetic resources. PPB programs of this sort have the potential to add value to local or traditional varieties that might otherwise be abandoned, thus promoting their *in-situ* conservation. The chapter briefly touches on methodologies to assess farmers' variety preferences. This is followed by sections that highlight some experimental designs for on-farm variety evaluation and farmer-participatory breeding methods for combining in-situ conservation with genetic improvement. Finally, some of the challenges that may limit genetic gain from PPB programs are noted - problems that increase the risk of wholesale replacement of on-farm genetic diversity rather than conservation through improvement.

Moving on to Chapter 12, this chapter examines seed systems and diversity. Farmers use various seed systems to obtain seeds for their next crop. The diversity of seeds determines, together with other aspects of the farming system, the biodiversity in farmed areas. Conservation strategies for crop genetic resources distinguish *ex situ*, on-farm and *in situ* components. The on-farm management of such resources is highly influenced by the seed systems that farmers use. Next to primary and secondary centres of diversity, this chapter introduces a tertiary source of diversity, based on the creation of new diversity through modern breeding. The impact of different seed systems on the management of crop genetic diversity is also analysed.

Chapter 13 concludes the book by providing an overview of DNA-based screening of Brassica germplasm for sustainable and enhanced crop production. The Brassica genus contains many agriculturally important oilseed and vegetable crops. Brassica germplasm, including natural accessions and breeding populations, are maintained globally for sustainable management

and enhancement of Brassica crop production which is critical to meet the demands of population growth and challenges of environmental stresses due to global climate change. DNA based markers, such as SNPs, are commonly used to screen large numbers of Brassica germplasm for conservation, genetic mapping and association studies. The chapter focuses on the application of SNP genotyping technologies for conservation of Brassica germplasm, uncovering the genetic basis of various biotic and abiotic stresses and screening for yield related traits and oil quality through marker-trait association studies.

# Chapter 1

---

## **Plant genetic resources for food and agriculture for sustainable development<sup>1</sup>**

*Chikelu Mba, Seeds and Plant Genetic Resources Team – Food and Agriculture Organization of the United Nations, Italy; M. Ehsan Dulloo, Bioversity International, Italy; and Kent Nnadozie, Secretariat of the International Treaty on Plant Genetic Resources for Food and Agriculture – Food and Agriculture Organization of the United Nations, Italy*

- 1 Introduction
- 2 Plant genetic resources for food and agriculture (PGRFA): a common concern for all countries
- 3 International agreements supporting the Global System on PGRFA
- 4 Global instruments supporting the global system on PGRFA
- 5 Global mechanisms supporting the global system on PGRFA
- 6 Codes of conduct and standards supporting the global system on PGRFA
- 7 The conservation of PGRFA
- 8 Pre-breeding and conservation of PGRFA
- 9 Plant breeding techniques to introduce desirable traits from PGRFA
- 10 Seed delivery systems
- 11 Conclusion
- 12 Where to look for further information
- 13 References

### **1 Introduction**

In 2019, about 2 billion people across the world lacked regular access to safe, nutritious and sufficient food (FAO, IFAD, UNICEF, WFP and WHO, 2020). This dire statistic, which mirrored the earlier estimation of about 2.5 billion people who suffer from various forms of nutrient deficiencies and obesity globally (FAO, IFAD, UNICEF, WFP and WHO, 2018, 2019), underscored a progressively

<sup>1</sup> The views expressed in this publication are those of the authors and do not necessarily reflect the views or policies of the Food and Agriculture Organization of the United Nations. This chapter is © Food and Agriculture Organization of the United Nations.

worsening state of global food insecurity and malnutrition. With increasing global population expected to reach 9.7 billion by 2050 (Anon, 2020), whereby the steepest increases are in food insecure countries of the developing South, it is estimated that 50% more food, over the 2013 baseline, needs to be produced by 2050 in order to meet the ever-increasing demands (FAO, 2017a). Yet, with climate change imperiling crop production systems, there are scarcely any redundant arable lands and water resources to be further deployed for food production. It is against this challenging backdrop that the world, through the Sustainable Development Goals (SDGs), committed to a world free of hunger and malnutrition in the next 10 years (UN General Assembly, 2015; FAO, 2017a).

The prohibitive economic and environmental costs and dangers to human health make the use of additional external inputs (such as agrochemicals) non-viable options for the significantly increased food production needed for a hunger-free world. Therefore, it is certain that a business-as-usual mind-set is not an option. In the absence of additional agricultural natural resources base for increased deployment and the impracticality of unbridled increases in the use of external inputs, the inherent potentials of our crops must be tapped to enhance their productivities, that is, producing more yields with fewer inputs. It is in this vein that the Food and Agriculture Organization of the United Nations (FAO) called for a new paradigm of sustainable crop production intensification (SCPI) in which a genetically diverse portfolio of improved crop varieties that are best suited to agroecosystem and farming practices and more resilient to climate change should be promoted (FAO, 2011). Similarly, the further development of agriculture, and the world's continued food security, will depend on farmers and breeders continuing to have access to and use diverse plant genetic resources necessary to face new environmental and social challenges.

Our optimism regarding the prospects of this paradigm derives from the knowledge that the first wave of crop domestication over 10 000 years ago resulted in the current agricultural systems on which the global food security and nutrition depend (McCouch, 2004; Waines and Ehdaie, 2007). The repertoire of wild ancestors or related species of crops - known as crop wild relatives (CWR); non-related species which are donors of heritable traits used in plant breeding; farmers' varieties or landraces and modern crop varieties is referred to as plant genetic resources for food and agriculture (PGRFA) (FAO, 2009). In essence, PGRFA are plants used, or with potentials to be used, for food and other agricultural purposes and therefore encompass the diversity of the plant kingdom that underpin global food security and nutrition. The values of crops, which are cultivated and harvested for food or other uses, and wild and undomesticated plants that are similarly exploited as food, are obvious. However, perhaps more importantly, PGRFA also serve as a huge reservoir of

heritable traits that enable crops to adapt to physical and biological stresses, for example, drought, heat, cold, pests and diseases – the direct consequences of climate change, and to enhance the nutritional attributes of crops (Mba et al., 2012).

The commitment of the international community to make PGRFA freely available, especially for research and development, through various normative processes and instruments is reviewed in the subsequent sections of this chapter. The actions that may be taken – through the conservation of PGRFA in situ and ex situ and the maintenance of on-farm diversity; their use in breeding progressively superior crop varieties; and delivery to farmers via effective seed systems to ensure that humanity benefits from these irreplaceable resources in ways that safeguard them for current and future generations are also highlighted. This chapter, in providing examples of these aspects of the conservation and sustainable use of PGRFA, also highlights the scientific and technological advances that make these possible. Finally, perspectives are shared on the imperative of the creation of the enabling environment and the fostering of winning partnerships for the sustainable management of PGRFA, especially with regard to unlocking their potentials through research and development.

## **2 Plant genetic resources for food and agriculture (PGRFA): a common concern for all countries**

Today, cassava – *Manihot esculenta* Crantz – is a far more important food security crop in sub-Saharan Africa into which it was first introduced by Portuguese sailors in the 16th century than in the countries, Brazil and Bolivia, which adjoin the Amazon basin where it was originally domesticated several tens of millennia ago. In like manner, oil palm – *Elaeis guineensis* Jacq. – with the evidence of its use as food dating as far back as five millennia in West Africa, its primary centre of genetic diversity, is a far more major cash crop in Asian countries, Malaysia and Indonesia, into which it was introduced a few decades ago.

Other crops such as maize, potatoes, wheat, barley and rice are now so ubiquitous around the globe that it is not obvious to the average consumer that they were introduced into most of the places where they have become seemingly irreplaceable staples. Also, the pioneering collecting expeditions of the likes of N.I. Vavilov and Jack Harlan early in the 20th century are well chronicled along with the concerns they raised about the decline in the diversity of crops as evidenced by the increasingly diminishing cultivation of traditional crop varieties or landraces and their undomesticated relatives, that is, CWR on-farm and in nature, respectively (Vavilov, 1931; Harlan, 1957).

These probably explain why the international community has consistently, while demonstrating the critical importance of PGRFA to global food security

and nutrition, also underscored the interdependence among nations as means to derive the most benefit from these resources. For instance, the FAO called for immediate action for the collection and conservation of landraces and CWR at the 10th session of its Conference in 1959. Following this, two major technical meetings in 1961 and 1967 took place. These were the Technical meeting on Plant Exploration and Introduction which was convened in 1961 to streamline germplasm conservation and distribution and established exploration centres in regions of greatest diversity (Scarascia-Mugnozza and Perrino, 2002). The 1967 International Technical Conference organized jointly by the FAO and the International Biological Programme (IBP) was a landmark conference that aimed to articulate a global strategy for the conservation of PGRFA. A Panel of Experts was constituted to develop the guidelines for the establishment of a global network for ex situ conservation and the associated plan of action (Frankel and Hawkes, 1975). The proposal of the Panel was presented at the 1973 FAO/IBP Technical Conference and subsequently was considered by the Technical Advisory Council of the CGIAR. This in turn led to the creation of a coordinating centre, the International Board on Plant Genetic Resources (IBPGR) in the FAO (which later became the CGIAR centre, the International Plant Genetic Resources Institute, later renamed Bioversity International and now the Alliance of Bioversity International and CIAT). The IBPGR was operated under the aegis of the FAO to promote and assist in the worldwide efforts to collect and conserve plant germplasm needed for future research and crop production (Scarascia-Mugnozza and Perrino, 2002).

Ever since, the international community, especially through the FAO's leadership, has been most active in emphasizing the interdependence of nations in both the responsibility of safeguarding PGRFA and the mutual benefits of using them. FAO's intergovernmental work on the conservation and use of PGRFA has been carried out through its Commission on Genetic Resources for Food and Agriculture (Commission) established in 1983 (FAO, 2010). Starting out as the Commission on Plant Genetic Resources and in 1995 taking on the responsibility for other components of agricultural biodiversity, it is an FAO forum for governments to discuss and negotiate matters relevant to genetic resources for food and agriculture. It is the only intergovernmental body that specifically deals with all components of biological diversity for food and agriculture. In this regard, it reviews and advises the FAO on policy matters, programmes and activities. It was in this vein that the Commission facilitated a Global System on Plant Genetic Resources for Food and Agriculture (Global System) which is a set of policy instruments and mechanisms to promote the safeguarding of PGRFA, their availability and sustainable use (FAO, 2010; Frison et al., 2011). The elements of the Global System and related international agreements are described in the following sections.

### **3 International agreements supporting the global system on PGRFA**

The principal international agreements supporting the Global System on PGRFA are:

- International Undertaking on Plant Genetic Resources for Food and Agriculture;
- The Convention on Biological Diversity (CBD); and
- The International Treaty on Plant Genetic Resources for Food and Agriculture.

These are discussed in the following sections.

#### **3.1 International undertaking on plant genetic resources for food and agriculture**

Adopted by the FAO's Conference in 1983, the objective of this undertaking was 'to ensure that plant genetic resources of economic and/or social interest, particularly for agriculture, will be explored, preserved, evaluated and made available for plant breeding and scientific purposes. This undertaking is based on the universally accepted principle that plant genetic resources are a heritage of mankind and consequently should be available without restriction' (FAO, 1983). This set the tone for the ongoing recognition and treatment of PGRFA as a global commonwealth.

#### **3.2 The convention on biological diversity (CBD)**

The CBD is the international agreement for 'the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources' (United Nations, 1993). Biodiversity encompasses PGRFA. In fact, the Strategic Plan for Biodiversity 2011–2020, including the Aichi Biodiversity targets, of the CBD is aimed at the promotion and the conservation and use, *inter alia*, of PGRFA. Aichi Target 13 specifically addresses the maintenance of the genetic diversity of cultivated plants, that is, crops, and their wild relatives. Also, Aichi Targets 7 and 13 address PGRFA explicitly. The Tenth Conference of Parties (or COP 10) of the CBD also endorsed the Global Strategy on Plant Conservation (GSPC) that addresses the challenges posed by threats to plant diversity. Target 9 of the GSPC aims at conserving 70% of genetic diversity of crops including their wild relatives. The post-2020 Biodiversity Framework, presently under negotiation, continues to highlight the contribution of genetic diversity to Nature's contribution to people and new targets for maintaining and

# Index

---

- ABA. *see* Abscisic acid (ABA)  
Abscisic acid (ABA) 199  
AFLP. *see* Amplified fragment length polymorphism (AFLP)  
African Orphan Crops Consortium 23  
African rice (*Oryza glaberrima* Steud.) 19  
Agreement between FAO and CBD 11  
Agrobiodiversity index 69, 71, 237  
Agrobiodiversity zones 237  
Agrochemicals 4  
AGUAPAN. *see* Association of Potato Biodiversity Guardians (AGUAPAN)  
Aichi Target 67  
Allozyme 66  
Amplified fragment length polymorphism (AFLP) 66  
*Arabidopsis thaliana* 289  
Arabidopsis transcription factor (HAG1) 309  
Asian rice (*Oryza sativa* L.) 19  
ASIC. *see* Association on the Study and Information on Coffee (ASIC)  
Association of Potato Biodiversity Guardians (AGUAPAN) 237  
Association on the Study and Information on Coffee (ASIC) 90  
Australia Grains Genebank (AGG) 290  
Automating processes 194–195  
  
Barcodes 193  
Bean farmers 255  
Biochemical markers 66  
Bioclimatic modelling 58  
Biodiversity conservation 103  
Biodiversity International's ClimMob 263  
Biodiversity mainstreaming platform 11  
Biodiversity seed fairs 234–235  
Blackleg resistance 300–301  
  
Botanic Gardens Conservation International 109  
Brahms database 160  
*Brassica* germplasm for sustainable and enhanced crop production  
DNA-based screening of 289  
enhancing yield and nutritional related traits 305–308  
management and conservation of 291–299  
seed quality 308–309  
sustainable management of resistance to abiotic stresses 303–305  
sustainable management of resistance to biotic stress 299–303  
Brazil CWR Seed Collecting Guide 158  
Breeder's exemption 281  
  
Card-based system 256  
Cardinal value 36  
Cassava 5  
Catch crops 279  
CBD. *see* Convention on Biological Diversity (CBD)  
CBD Biodiversity Strategic Plan 2011–2020 67  
Centre for Pacific Crops and Trees (CePaCT) 46, 141  
CePaCT. *see* Centre for Pacific Crops and Trees (CePaCT)  
CGIAR cost analysis 39  
CGIAR. *see* Consultative Group for International Agricultural Research (CGIAR)  
CGN. *see* Genetic Resources the Netherlands (CGN)  
CGRFA. *see* Genetic Resources for Food and Agriculture (CGRFA)

- Chloroplast DNA (cpDNA) markers 66
- CIAT. *see* International Center for Tropical Agriculture (CIAT)
- CIMMYT 223
- Climate change species distribution modelling in Oman 112-114
- Club approach 95-96
- Clubroot resistance 301-302
- Clustered regularly interspaced palindromic repeat (CRISPR) 20
- COGENT. *see* International Coconut Genetic Resources Network (COGENT)
- Cold acclimation 201
- Collaboration 88
- Collaboration pattern
  - domestic and foreign partners 86
  - domestic partners by subsectors 87
  - foreign partners (OECD/non-OECD) 86
- Collaborative initiatives 89
- Collecting crop wild relatives
  - collecting and post-harvest handling, techniques for 172-177
  - collecting seed at correct time 164-166
  - future research directions 177-179
  - identifying target CWR taxa successfully 160-162
  - sampling genetic diversity effectively 169-171
  - seed development/ripening/dispersal, understanding 162-164
  - seed quality and quantity, assessing 167-169
  - targeting species and regions 157-160
  - techniques and key issues in 155
- Collecting Plant Genetic Diversity technical guidelines 158
- Collective logic stems 88
- Community-based conservation
  - autonomous community-based conservation
    - cultural factors 231-233
    - provisioning functions 233
    - regulating functions 233-234
  - of crop genetic resources 229
  - exogenous incentives 234-238
  - monitoring 238-239
- Community seed banks (CSB) 235
- Complementary conservation 122-126
- Compositional diversity 90
- Conservation into utilization 127-129
- Conservation planning 108
- Conservation products 126-127
- Conservation techniques 122
- Consultative Group of International Agronomic Research Centers (CGIAR) 8, 83, 223
- Convention on Biological Diversity (CBD) 7-8, 159, 278
- Core, Darwin 175
- Corporate Social Responsibility (CSR) 237
- Cover crops 279
- CPC Best Plant Conservation Practices 175
- CRISPR. *see* Clustered regularly interspaced palindromic repeat (CRISPR)
- CRISPR/Cas systems 20
- CRISPR/Cas9 systems 20
- Crop diversity 233
- Crop landraces (LR) 105
- Crop Trust 142-143
- Crop wild relatives (CWR) 4, 57, 105, 155
- Cryo-plate procedure 204
- Cryopreservation 200
- CSB. *see* Community seed banks (CSB)
- CSR. *see* Corporate Social Responsibility (CSR)
- Cultural affirmation 236
- Cut test 168
- CWR Conservation Planning Toolkit 116
- CWR Diversity 116
- CWR Global Portal 116
- CWR taxa 111
- CWR. *see* Crop wild relatives (CWR)
- DArTseq. *see* Diversity Array Technology sequencing (DArTseq)
- Deoxyribonucleic acid (DNA) 20
- Dimethyl thiourea (DMTU) 203
- Diphenyleneiodonium (DPI) 203
- Dispersal bottleneck 272
- Diversity Array Technology sequencing (DArTseq) 290
- Diversity of values 47-48
- DMTU. *see* Dimethyl thiourea (DMTU)
- DNA. *see* Deoxyribonucleic acid (DNA)
- DNA-based screening, *Brassica* germplasm 292-298
- Domestication 272
- Dong Van Karst Plateau Geopark 237
- DPI. *see* Diphenyleneiodonium (DPI)
- Drought tolerance 304
- Dry fruits, ripening of 162
- Dry indehiscent fruits 166
- Duplication sites 126

- Ecogeographic land characterization (ELC)  
maps 119
- Ecogeographical representativeness 158
- Ecogeography/gap analysis 114-120
- Economic value 36
- Ecosystems services 232
- Elaeis guineensis* Jacq. (oil palm) 5
- Electronic data collection 193
- Encapsulation-dehydration technique 204
- ENSCONET 167
- Equilibrium Relative Humidity (eRH) 166
- Equity logic stems 88
- eRH. see equilibrium Relative Humidity (eRH)
- EURISCO 109
- Euro construction upgrade project 221
- Expected heterozygosity (He) 66
- Ex situ conservation 14-15  
automating processes  
germination scoring 198  
robotic storage and retrieval 195-196  
seed phenotyping 196-197  
seed sorting 197-198  
management of orthodox seeds,  
improving  
changing procedures 190-194  
routine operations 186-190  
new technologies to improve 185  
recalcitrant seeded and vegetatively  
propagated species, management of  
changing procedures 202-205  
routine operations 198-202
- Facilitated access 94
- FAO. see Food and Agriculture Organization (FAO)
- FAO/CGRFA National focal points 85
- FAO/IBP Technical Conference (1973) 6
- FCA. see Four-cell analysis (FCA)
- Flagship species 111
- Fleshy fruits 165
- Flowering and fruiting, variation in 164-165
- Flowering time 306-307
- Food and Agriculture Organization (FAO) 4
- Food Gastronomic Integration  
Movement 231
- Food security 233
- Food security policies 280
- Four-cell analysis (FCA) 63
- Frost tolerance 304
- GAB. see Genomics-assisted breeding (GAB)
- Gap analysis 115
- GBIF. see Global Biodiversity Information Facility (GBIF)
- GBS-t. see GBS-transcriptomics (GBS-t)
- GBS-transcriptomics (GBS-t) 299
- Genebank information systems 190
- Genebank standards 12
- Genebanks, valuing plant genetic resources in  
current research on 40-46  
future trends in 47-48  
past research on 37-40
- GENESYS 109
- Genesys-PGR 176
- GENESYS Platform 12
- Genetic diversity 65
- Genetic erosion 35, 65
- Genetic modification 20
- Genetic resource policies 281
- Genetic Resources for Food and Agriculture (CGRFA) 219
- Genetic Resources the Netherlands (CGN) 148
- Genetic sampling strengthened, knowledge of 177-178
- Genome editing 20-22
- Genome-wide association studies (GWAS) 16
- Genome-wide or genomics selection (GS) 22
- Genomics-assisted breeding (GAB) 22
- Germination scoring 198
- Germplasm exchange 85
- Germplasm Resources Information Network (GRIN) 109, 300
- Germplasm, sources of 83
- Global Benefit Sharing Fund 93
- Global Biodiversity Information Facility (GBIF) 59, 116, 156
- Global coordination 25
- Global Crop Diversity Trust (Crop Trust) 12, 37
- Global environment facility 12
- Global exchange of germplasm for crop breeding  
black box of collaborations, opening the actors 91-92  
institutions 88-89  
organizations 89-90  
relations 90-91  
resources 87-88  
germplasm exchange fallacies 92-96  
improving the 81

- Global instruments supporting the global system on PGRFA  
 first report 9  
 GPA 9  
 second GPA 9  
 second report 9  
 state of world's biodiversity, report 10
- Global Musa Genetic Resources Network (MUSANET) 141
- Global Strategy on Plant Conservation (GSPC) 7
- Greek national genebank 40
- Green Revolution 16-18
- GRFA stakeholders 85
- GRIN. *see* Germplasm Resources Information Network (GRIN)
- GRIN-Global 38, 190
- Group ranking exercises 256
- GS. *see* Genome-wide or genomics selection (GS)
- GSPC. *see* Global Strategy on Plant Conservation (GSPC)
- GWAS. *see* Genome-wide association studies (GWAS)
- Harlan and de Wet CWR Inventory 156
- Harlan, Jack 5
- He. *see* Expected heterozygosity (He)
- Heat tolerance 303
- Herbarium vouchers and associated botanical collections 173-175
- Hermetically sealed barrel 174
- Heterozygosity 66
- Ho. *see* Observed heterozygosity (Ho)
- Hordeum chilense* excerpt 161
- Hydrated-storage 199
- IARCs. *see* International Agricultural Research Centres (IARCs)
- IBP. *see* International Biological Programme (IBP)
- IBPGR. *see* International Board for Plant Genetic Resources (IBPGR)
- ICAR. *see* Indian Council of Agricultural Research (ICAR)
- ICARDA withdrawal and re-deposit programme 223-224
- ICARDA. *see* International Center for Agricultural Research in the Dry Areas (ICARDA)
- ICRISAT. *see* International Crop Research Institute for the Semi-Arid Tropics (ICRISAT)
- In situ conservation 13-14
- iNaturalist 176
- Inclusive approach 96
- InDels 22
- Indian Council of Agricultural Research (ICAR) 64
- Induced mutagenesis 18-19
- Insect resistance 302-303
- In situ* and *ex situ* conservation  
 advantages 124  
 disadvantages 124
- Integrative index (HT\*) 71
- Intellectual property policies 281-282
- Intermixed gene pools 291
- International Agricultural Research Centres (IARCs) 223
- International Biological Programme (IBP) 6
- International Board for Plant Genetic Resources (IBPGR) 6, 140
- International Center for Agricultural Research in the Dry Areas (ICARDA) 42
- International Center for Tropical Agriculture (CIAT) 42, 64
- International Coconut Genetic Resources Network (COGENT) 141
- International code of conduct for plant germplasm collecting and transfer 11-12
- International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) 223
- International endeavours 12
- International Institute for Agricultural Research in Dry Areas (ICARDA) 223
- International Maize and Wheat Improvement Center (CIMMYT) 223
- International Network of *Ex Situ* Collections 10-11
- International Plant Names Index (IPNI) 116-117
- International Potato Center (CIP) genebank 41
- International Rice Genebank (IRG) 41
- International Rice Research Institute (IRRI) 37, 194
- International Rice Research Institute 191
- International Technical Conference (1967) 6
- International Transfer Centre (ITC) 147
- International Treaty for Plant Genetic Resources for Food and Agriculture (ITPGRFA) 7, 84, 140, 219, 278

- International Undertaking on Plant Genetic Resources for Food and Agriculture 7
- International Union for the Protection of New Varieties of Plants (UPOV) 84
- IPNI. *see* International Plant Names Index (IPNI)
- IRG. *see* International Rice Genebank (IRG)
- IRRI. *see* International Rice Research Institute (IRRI)
- ITC. *see* International Transfer Centre (ITC)
- ITPGFRA. *see* International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGFRA)
- IUCN Red List 117
- Joint Division of the Food and Agriculture Organization of the United Nations and the International Atomic Energy Agency (Joint FAO/IAEA) 18
- Joint FAO/IAEA. *see* Joint Division of the Food and Agriculture Organization of the United Nations and the International Atomic Energy Agency (Joint FAO/IAEA)
- Kaempferol 3-O-sinapoyl-sophoroside 7-O-glucoside (KSSG) 302
- Kompetitive allele-specific PCR (KASP) markers 290
- KSSG. *see* Kaempferol 3-O-sinapoyl-sophoroside 7-O-glucoside (KSSG)
- Landraces, repatriation of 235
- Late embryogenesis abundant (LEA) protein 304
- Leibniz Institute of Plant Genetics and Crop Plant Research 290
- Lens culinaris* subsp. *orientalis*, distribution of 119
- Living in harmony with Nature 68
- MAGIC. *see* Multiparent advance generation intercross (MAGIC)
- Manihot esculenta* Crantz (cassava) 5
- Marker-aided selection (MAS) 16, 22–23
- Marker-assisted recurrent selection (MARS) 22
- Market-based approaches 235–236
- MARS. *see* Marker-assisted recurrent selection (MARS)
- MAS. *see* Marker-aided selection (MAS)
- Mass selection 261–262
- Mexican CWR 177
- Millennium Seed Bank (MSB) 156, 187
- Millennium Seed Bank Partnership (MSBP) 157
- Mixed ripeness collections 173
- MLS. *see* Multilateral System of Access and Benefit Sharing (MLS)
- Modern cultivars 105
- Modernization bottleneck 273
- Molecular markers 66
- Monitoring genetic diversity 61–67
- Monitoring plant genetic resources  
   monitoring genetic diversity 65–67  
   monitoring species diversity 57–61  
   monitoring varietal diversity 61–64  
   targets and indicators framework 67–69
- Monitoring species diversity  
   geographical distribution and habitat diversity 59  
   phenology and biotic interactions 60  
   species richness/abundance/  
     demographics 59–60  
   threat status 61
- Mother-baby trial designs 258–259
- MSB. *see* Millennium Seed Bank (MSB)
- MSBP. *see* Millennium Seed Bank Partnership (MSBP)
- Multilateral System of Access and Benefit Sharing (MLS) 84
- Multiparent advance generation intercross (MAGIC) 16
- Multiple dependencies 88
- Musa global conservation strategy 147
- MUSANET. *see* Global Musa Genetic Resources Network (MUSANET)
- Mutant Varieties Database (MVD) 18
- MVD. *see* Mutant Varieties Database (MVD)
- Nagoya Protocol 94
- NAM. *see* Nested association mapping (NAM)
- National Geospatial-Intelligence Agency (NGA) 117
- National Laboratory for Genetic Resources Preservation (NLGRP) 156
- National Strategic Action Plans 13
- Nationally Important National Agricultural Heritage Systems (NIAHS) 237
- Natural seed dispersal, cues for 165–166
- NBS-LRR candidate genes 302
- Need-based plant breeding 18
- Neglected and underutilized species 231

- NERICA. *see* New Rice for Africa (NERICA)
- Nested association mapping (NAM) 16
- Network connectivity 90
- New Rice for Africa (NERICA) 19
- New-generation sequencing (NGS) 22, 66
- NGA. *see* National Geospatial-Intelligence Agency (NGA) 117
- NGS. *see* New-generation sequencing (NGS)
- NIAHS. *see* Nationally Important National Agricultural Heritage Systems (NIAHS)
- NLGRP. *see* National Laboratory for Genetic Resources Preservation (NLGRP)
- Non-food socio-economic species 106
- NordGen. *see* Nordic Genetic Resource Centre (NordGen)
- Nordic Genetic Resource Centre (NordGen) 219
- North American CWR 177
- Northeast Regional Plant Introduction Station 290
- Norwegian Ministry of Foreign Affairs 218
- Nor-Yaayos Cochas Landscape Reserve 237
- Nucleotide diversity ( $\Pi$ ) 66
- Observed heterozygosity ( $H_o$ ) 66
- Obsolete cultivars 105
- Oil palm (*Elaeis guineensis* Jacq.) 5
- On-farm management 14
- Online Reporting Tool (ORT) 45
- Open Data Kit software 176
- ORT. *see* Online Reporting Tool (ORT)
- Park and protected zone systems 237–238
- Participatory plant breeding (PPB) 253
  - based on traditional/local varieties
    - challenges and limitations 264–265
    - mass selection 261–262
    - selection among vs. within populations 262
    - selection in later stages of breeding process 263
    - stratified mass selection 262
  - methodologies to assess variety preference
    - experimental designs for evaluation 257–258
    - gathering farmer input 254–257
    - mother-baby trial designs 258–259
    - tricot design 259–261
- Payment for environmental services (PES) 236–237
- Pentatricopeptide repeat (PRR) protein 303
- PES. *see* Payment for environmental services (PES)
- PGR conservation strategies and techniques 122
- PGR conservation techniques 123
- PGR taxa 111
- Phenology and biotic interactions 60
- Plackett Luce model 260
- Plant Book 117
- Plant Exploration and Introduction (1961) 6
- Plant genetic conservation and use 107
- Plant genetic resources
  - conservation
    - complementary conservation 122–126
    - into utilization 127–129
    - products of 126–127
    - techniques 122
  - conservation and use of, key steps in 103
  - conservation planning
    - conservation objectives 120–121
    - ecogeography/gap analysis 114–120
    - field surveys 120
    - project commission 114
    - target taxa, selection of 108–114
- Plant genetic resources, diversity of 105
- Plant Genetic Resources Center (SPGRC) 141
- Plant genetic resources for food and agriculture (PGRFA)
  - codes of conduct and standards
    - supporting global system on 11–12
  - common concern for all countries 5–6
  - conservation of 12–15
  - global instruments supporting the global system on 8–10
  - global mechanisms supporting the global system on 10–11
  - international agreements supporting the global system on 7–8
  - plant breeding techniques 16–23
  - pre-breeding and conservation of 15–16
  - seed delivery systems 23–24
- Plant Genetic Resources for Food and Agriculture under Development' category 87
- Plant List, the 117
- PlantNet 176
- Points sampling 171

- Portable hygrometer 167  
 Post-harvest seed handling  
     recommendations 173  
 Post-WWII era 89  
 Potato park 238  
 PPB. *see* Participatory plant breeding (PPB)  
 PRATEC movement 236  
 Pre-breeding and conservation PGRFA 15-16  
 Pre-growth 204  
 Pre-growth-dehydration 204  
 Preserving crop genetic diversity *ex situ*  
     composition of *ex situ* collections,  
         issues 143-144  
     routine operations, issues 144-149  
     use of conserved genetic resources,  
         issues 149-150  
 Pressed plant (herbarium) specimens 173  
 Project commission 114  
 Protected planet 117  
  
 QMS. *see* Quality management system (QMS)  
 QTL mapping 302  
 QTL. *see* Quantitative trait loci (QTL)  
 Quality management system (QMS) 148  
 Quality-declared seed classes 272  
 Quantitative trait loci (QTL) 16  
  
 RBC. *see* Registry of Base Collections (RBC)  
 Recalcitrant seeds 173  
 Registry of Base Collections (RBC) 140  
 Research knowledge, deployed 178-179  
 Restriction length polymorphisms (RFLPs) 66  
 Restriction-site Associated DNA sequencing  
     (RAD-seq) 290  
 Revising monitoring intervals 191-192  
 Rice Terraces of Cordilleras 237  
 Robotic storage and retrieval 195-196  
 Robust information system 190  
  
 SADC. *see* Southern Africa Development  
     Community (SADC)  
 Safety duplication 219  
 Salinity tolerance 305  
 SBSTTA. *see* Subsidiary Body on Scientific,  
     Technical and Technological Advice  
     (SBSTTA)  
 SCPI. *see* Sustainable crop production  
     intensification (SCPI)  
 SDGs. *see* Sustainable Development Goals  
     (SDGs)  
 SDM. *see* Species distribution modelling  
     (SDM)  
  
 Seed and genetic modification  
     regulations 282-283  
 Seed coat 307-308  
 Seed collecting 172-173  
 Seed delivery systems 23-24  
 Seed development, biology of 162-163  
 Seed drying 190-191  
 Seed genebanking 185  
 Seed Information Database (SID) 191, 194  
 Seed morgues 47  
 Seed phenotyping 196-197  
 Seed quality 308-309  
 'Seeds of Discovery' initiative 144  
 Seed sorting 197-198  
 Seed storage 185  
 Seed systems 271-272  
 Seed systems and diversity  
     in farmers' fields 273-274  
     in formal seed systems  
         creating diversity within variety  
             279-280  
         creating new diversity 278-279  
         increasing differences between  
             varieties 278  
         increasing the number of  
             varieties 277-278  
     policies and regulations  
         food security policies 280  
         future trends in research 283  
         genetic resource policies 281  
         intellectual property policies 281-282  
         seed and genetic modification  
             regulations 282-283  
         supporting diversity 274-277  
 Seed yield 305-306  
 Seedlinked 263  
 Seeds Toolkit 23  
 SEPLs. *see* Socio-Ecological Production  
     Landscapes (SEPLs)  
 Sequence-tagged sites (STS) 66  
 SHW. *see* Synthetic hexaploid wheat (SHW)  
 SID. *see* Seed Information Database (SID)  
 Simple sequence repeats (SSR) 66  
 Single nucleotide polymorphisms  
     (SNPs) 22, 66, 290  
 Single-logic bias 92-94  
 Single-resource bias 92, 94-95  
 Single-transactional bias 93  
 SLAF-seq. *see* Specific-Locus Amplified  
     Fragment Sequencing (SLAF-seq)  
 SNP. *see* Single Single nucleotide  
     polymorphism (SNP)

- Socio-Ecological Production Landscapes (SEPLs) 71
- Solanum asperolanatum* 164
- SOP. *see* Standard operating procedures (SOP)
- Southern Africa Development Community (SADC) 141
- Species distribution modelling (SDM) 111
- Specific-Locus Amplified Fragment Sequencing (SLAF-seq) 299
- SPGRC. *see* Plant Genetic Resources Center (SPGRC)
- SSR resistance 301
- SSR. *see* Simple sequence repeats (SSR)
- Standard handling methods, sensitive to 178
- Standard operating procedures (SOP) 148
- Standard World Floras 117
- Storage sites 126
- Stratified mass selection 262
- STS. *see* Sequence-tagged sites (STS)
- Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) 25
- Surveillance monitoring 58
- Sustainable crop production intensification (SCPI) 4
- Sustainable Development Goals (SDGs) 4, 35, 67
- Svalbard Global Seed Vault 12, 14, 146  
 case study 223–224  
 facility and operation 220–223  
 in global context 219–220  
 in preserving crop genetic diversity, role storing seeds in Arctic 218–219
- Synthetic hexaploid wheat (SHW) 42
- TAL (transcription-activator-like) effector nucleases (TALENs) 20, 279
- TALENs. *see* TAL (transcription-activator-like) effector nucleases (TALENs)
- Targeted monitoring 58
- Target taxa, selection of  
 biological importance 110  
 climate change 111  
 conservation agencies, priorities of 111  
 conservation sustainability 110  
 cultural importance 110  
 current conservation status 108–109  
 ecogeographic distinction 109  
 ethical and aesthetic considerations 111  
 legislation 110  
 native status 109–110  
 perceived threat 109  
 relative cost of conservation 110  
 socio-economic use 108  
 taxonomic and genetic distinction 109
- Threat status 61
- Tissue culture 19
- Transaction bias 95–96
- TRANSPARENT TESTA 12 (TT12) gene 308
- Triadic comparisons of technologies 259
- Tricot design 259–261
- Tropicos 116
- Tumult 280
- UK National Tree Seed project 170
- U.S. National Plant Germplasm System 43
- Unadapted materials 15
- United Nations Sustainable Development Goals 185
- UPOV. *see* International Union for the Protection of New Varieties of Plants (UPOV)
- US National Plant Germplasm System (US NPGS) 40
- Variable number of tandem repeats (VNTR) analysis 66
- Vavilov, N. I. 5
- Viability testing 193–194
- Vitrification techniques 204
- Warwick Genetic Resource Unit 290
- Weedy races 105
- Whole genome resequencing (WGR) 290
- WIEWS. *see* World information and early warning system of plant genetic resources for food and agriculture (WIEWS)
- Wild harvested plant species 106
- Willingness-to-pay (WTP) 40
- Winter Cereals Collection 40
- World Agroforestry genebank 43
- World information and early warning system of plant genetic resources for food and agriculture (WIEWS) 10
- World Vegetable Center 45
- World's reliance on narrow diversity of food crops 104
- WTP. *see* Willingness-to-pay (WTP)
- ZFNs. *see* Zinc-finger nucleases (ZFNs)
- ZincFinger 279
- Zinc-finger nucleases (ZFNs) 20